

DEVELOPMENT AND FABRICATION OF AN INSTRUMENT  
TO  
MEASURE INTEGRATED SKIN TEMPERATURE

CONTRACT NAS 9-4067

FINAL REPORT

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LIFE SYSTEMS DIVISION

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B. D. CULVER, M.D., MANAGER  
LIFE SYSTEMS DIVISION

  
E. M. PRUDDEN  
PROJECT MANAGER

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## I. INTRODUCTION

This final report summarizes the results of work conducted by Aerojet-General Corporation under NASA Contract NAS 9-4067 toward development of an instrument to measure integrated skin temperature. A technical description of the delivered hardware is provided in the existing "Technical Manual, Operation and Maintenance, Skin Temperature Measuring Instrument," Aerojet document No. IS-0953, dated November 1965. Reference to this document is made throughout the following discussion.

## II. PROGRAM SUMMARY

Aerojet-General Corporation commenced work on this program in April, 1965 under NASA Contract NAS 9-4067, issued by the NASA Manned Space Flight Center, Procurement and Contracts Division, General Research Procurement Branch, Houston, Texas. Specific technical and program requirements are delineated in the contract statement of work. In summary, the contract called for the development, fabrication and delivery of an instrument to measure an integrated skin temperature over most of the body with the sensor portion of the instrument used either alone or inside a pressure suit. It was specified that the instrument sensors were to be incorporated into an MSC supplied liquid cooled undergarment. In addition to measuring an integrated temperature of the entire body, it was specified that the instrument was to indicate the individual integrated temperatures for the forearms, total arms, chest, back, lower trunk, thighs and legs. Specified accuracy for the instrument was  $\pm 0.1^{\circ}\text{F}$ .

Consistent with the specified requirements, Aerojet employed the principle of resistance thermometry in the design of the subject instrument. As described and illustrated in detail in the operation and maintenance manual (Aerojet document IS-0953), the instrument is comprised of two major units consisting of a console and the suit (Figure 1). A highly stable constant current dc source housed in the console continuously supplies a fixed current to all sensor wire circuits inside the suit. The sensor wires are affixed inside the suit on flexible strips of cotton knit cloth in such a manner that

the wire temperature closely follows body surface temperatures that exist over specified areas of the body. A differential voltmeter in the console is used to measure precise voltage drops across selected sensor circuits. Since a constant current flow is continuously maintained in each sensor circuit, the measured voltage is always directly proportional to the resistance in the selected sensor circuit, which in turn is directly proportioned to the temperature of the sensor wire. Thus by calibrating the instrument in terms of voltage change per unit of temperature change, it is possible to interpret body surface temperatures directly in terms of readout voltage.

During the development of the subject instrument, several problems were encountered that prevented Aerojet from meeting the originally contracted delivery date of 7 September 1965. These were (1) late delivery of the differential voltmeter and a special switch from the suppliers, (2) recurrent breakage of the original 2 mil diameter sensor wire and (3) general failure of the sensor wire electrical insulation. The first two problems resulted in modification No. 2 to the contract, wherein the delivery was rescheduled to 22 December 1965. The third problem resulted in modification No. 3 to the contract, setting the delivery schedule back to 30 May 1966. Modification No. 1 to the contract was a routine NASA action reflecting changes to the NASA Industrial Property Control Manual.

The problem with breakage of the 2 mil wire was overcome by changing to a 4 mil diameter wire. The wire insulation problem was effectively countered by changing from the original Isonel (Schenectady Chemicals Co., ) insulation to Formvar (G. E. patented, poly-vinyl-acetal enamel) insulation. Final test samples prepared with Formvar performed very well under dry or moderately damp body conditions. Considerable current leakage was detected, however, when the samples were tested while submerged in a 0.85% Na Cl solution in water (simulated sweat bath solution). The final suit was assembled with the Formvar insulated wire, which is the best insulation technology for this application known to Aerojet at this time.

On 24 May 1966, the components of the completed instrument were integrated and functionally tested at MSC by Aerojet personnel. On 25 May 1966,

Aerojet personnel assisted MSC personnel in calibrating the instrument and in running performance tests in conjunction with the MSC temperature controlled manikin. All tests were satisfactorily completed. The instrument performed within specified accuracy limits in all respects. The tests at MSC did not consider operation under damp suit conditions.

### III. TECHNICAL DISCUSSION

#### A. SYSTEM

Figure 2 is a block diagram showing the interrelation between the various major components of the system. Figure 3 is a functional schematic diagram of these components which provides a basis for understanding the following discussions. A detailed schematic diagram of the system is provided in the operation and maintenance manual (Aerojet document No. IS-0953).

##### 1. Functional Description

Referring to Figure 3, a constant current  $I = 7.0 \text{ ma}$  is generated by the constant current dc source. This current is passed through the series connected sensor circuits which are placed inside of the T-suit. The sensor circuits are made of insulated high purity nickel wire, and each separate circuit is of a different length (and thus resistance) as necessary to cover the area of the body over which it must sense integrated skin temperature. A sampling selector switch is used to select the desired sensor circuit across which the voltage drop is to be measured by a differential voltmeter. The selector switch is connected in such a manner that it grounds the node of the sensor circuit being measured, thereby providing a common reference point for all voltage measurements. Balancing resistors are connected in series with each sensor circuit such that the voltage drop across each selected sensor circuit can be adjusted to approximately the same voltage level for any selected calibration (body) temperature. A fault indicator and protection circuit is connected across each sensor circuit in such a manner as to limit the maximum voltage that can be developed across a break in any sensor wire

to a safe level, and to provide pilot light indication that a break has occurred in that circuit. Finally, a current output limiter circuit is provided to limit the maximum voltage and current out of the constant current source to a safe level should all sensor circuits experience a simultaneous break.

## 2. Performance Parameters

The total voltage measured by the differential voltmeter is the sum of the voltage drops across the selected T-suit sensor circuit and its associated balancing resistors, with a constant 7.0 ma dc impressed through them. The balancing resistors were specially selected for their low thermal coefficients of resistivity, to the extent that their extremely small resistance variation over the specified operating temperature range is within an allowable range that meets the  $\pm 0.1^\circ\text{F}$  accuracy specified for the overall instrument. Consequently, within the specified accuracy limits, the only changes in voltage the differential voltmeter sees are those due to the change of resistance of the selected sensor circuit as caused by body temperature change. This change in resistance vs. temperature is linear in the range  $0^\circ\text{C}$  to  $100^\circ\text{C}$  for the high purity nickel wire used in the sensor circuits, and can be expressed in terms of resistance  $R_t$  at any temperature  $T$  above the basic resistance  $R_0$  at  $0^\circ\text{C}$  by the equation:

$$R_t = R_0 (1 + \alpha T)$$

$$\text{or; } R_t = R_0 + R_0 \alpha T$$

Where  $\alpha$  is the thermal coefficient of resistance, which for the high purity nickel sensor wire is 0.00676 in the range  $0^\circ\text{C}$  to  $100^\circ\text{C}$ . The change of sensor circuit resistance in the T-Suit over a temperature change from  $T_1$  to a temperature  $T_2$  can thus be expressed as:

$$\Delta R = (R_0 + R_0 \alpha T_1) - (R_0 + R_0 \alpha T_2)$$

$$\text{or; } \Delta R = R_0 \alpha (T_1 - T_2)$$

The change in voltage drop across the sensor circuit over the same temperature range can thus be expressed:

$$\Delta V = I \Delta R = I R_0 \alpha (T_1 - T_2)$$

If the temperature of the sensor circuit is set to a known level  $T_c$  and the voltage drop  $V_c$  across the sensor circuit is measured at that temperature, the voltage  $V_x$  that will be measured at any other temperature  $T_x$  within the operating range becomes:

$$V_x = V_c \pm \Delta V$$

$$\text{or; } V_x = V_c \pm I R_0 \alpha (T_x - T_c)$$

Solving for  $T_x$  we have:

$$T_x = T_c + \left( \frac{V_x - V_c}{I R_0 \alpha} \right)$$

The expression  $I R_0 \alpha$  represents the change in voltage drop per degree of temperature change within the sensor element. Since  $I$  and  $\alpha$  are constants,  $I R_0 \alpha$  is a different constant for each individual sensor circuit, depending upon its basic resistance value  $R_0$ . The value of  $I R_0 \alpha$  for each sensor is measurable by setting the temperature of each sensor to two different levels and measuring the corresponding voltage drop at each level. The resulting  $\Delta V$  per degree temperature change (either  $^{\circ}\text{F}$  or  $^{\circ}\text{C}$  depending on the units used for  $T_c$ ) for each sensor thus establishes the corresponding constant value  $K_{1---n}$  for the expression  $I R_0 \alpha$ . The final expression for determining the unknown temperature  $T_x$  of any sensor 1 --- n in terms of measured voltage drop  $V_x$  thus becomes:

$$T_x = T_c + \left( \frac{V_x - V_{cl---n}}{K_{1---n}} \right)$$

Where  $T_c$  is any selected calibration temperature in the specified operating range of  $50^{\circ}\text{F}$  to  $100^{\circ}\text{F}$ ;  $V_{cl---n}$  is the voltage drop across any selected sensor circuit measured by the differential voltmeter at temperature  $T_c$ ; and  $K_{1---n}$  is the constant for the selected sensor circuit expressed in terms of voltage drop change across the sensor circuit per  $1^{\circ}\text{F}$  change in sensor temperature.

The basis for calibrating and using the instrument in determining unknown body temperatures was thus established. That is, by placing the suit on the temperature controlled manikin at MSC, and establishing a known suit temperature of  $T_c$  within the specified  $50^{\circ}\text{F}$  to  $100^{\circ}\text{F}$  operating range, the value of  $V_c$  can be measured by the differential voltmeter for each individual sensor circuit that the instrument is capable of selecting. Then, by changing the value of  $T_c$  to  $T_c \pm$  several degrees, and again measuring corresponding sensor circuit voltage drops, the value of  $K$  can be determined for each circuit. Thus with the values of  $V_c$  and  $K$  known for each sensor circuit, the unknown temperature  $T_x$  at any other level from  $50^{\circ}\text{F}$  to  $100^{\circ}\text{F}$  can be determined by reading the corresponding voltage drop value  $V_x$  and substituting into the above equation.

## B. COMPONENTS

The following discusses the various major components of the instrument as shown in block form in Figure 2 and in functional schematic form in Figure 3:

### 1. Constant Current Source

Recent advances in the state-of-the-art of constant current source dc power supplies were instrumental in enabling the development of a skin temperature measuring instrument that can be conveniently operated within the accuracies required. The current source selected was the Princeton Applied Research Corporation Model TC-100.2R. This source provides short-term (8 hour) current stability from 0 to 100 milliamps within  $\pm 0.002\%$  of the set current level, and long-term (30 days) stability of  $\pm 0.02\% \pm 200$  millimicroamps. In this application the constant current source is operated continuously at a nominal 7.0 ma output level, at which level the load regulation is less than 1.0 microamp. Temperature stability is  $\pm 0.005\%$  of the set output current from  $15^{\circ}\text{C}$  to  $35^{\circ}\text{C}$ .

### 2. Balancing Resistors

Since each sensor circuit has a different basic resistance due to their various lengths, balancing resistors were connected in

series with each individual sensor circuit of the suit for the purpose of balancing the measured voltage drop across each circuit to approximately the same level when the instrument is calibrated at a set temperature reference level (See Figure 1-2 of operation and maintenance manual LS-0953, resistors R1-R4 and R6-R14). By means of these resistors the constant current source is presented with a minimum load variation, consistent with the high accuracy requirements. Further, the balancing resistors afford an operating convenience in that they limit the operating voltage range within which the differential voltmeter must be adjusted during normal operation. Finally, the balancing of these voltages enables the application of standardized safety circuits to each individual sensor circuit (See Section III B.3 below).

Since these resistors are a part of the temperature measuring circuits, their individual thermal coefficients of resistance have an effect on readout accuracies. To compensate for this effect, the original design called for the resistors to be placed in a temperature regulated module. Further consideration showed that the required accuracies could be better achieved by eliminating the temperature controlled module and replacing the original balancing resistors with low temperature coefficient resistors. This change was made before the console was shipped to MSC, and is documented in a May 1966 errata sheet to the operation and maintenance manual, LS-0953.

### 3. Safety Circuits

A fault indication and protection circuit is provided in conjunction with each individual sensor circuit. These circuits are connected such that a broken sensor element in any circuit within the suit results in the illumination of a corresponding pilot light as well as shunting of the circuit within the console to prevent the development of harmful voltages across the break. A broken element results in total source voltage being applied across the associated fault indication and protection circuit, triggering a silicon controlled rectifier. With the silicon controlled rectifier energized, the respective indicator lamp

denotes which circuit is defective. In addition, the fault indicator and protection circuit will limit the voltage across the break to 5.0 vdc at 7 ma through a voltage regulator consisting of a Zener reference diode and resistor. A secondary protective circuit, consisting of a Zener diode and resistor connected into the constant current source output, limits the voltage to 33 vdc maximum at 7 ma in the event that all temperature sensing elements should fail.

Breaks in individual sensor circuits do not affect the operation or accuracy of the remaining circuits. The regulated 7 ma bias current is maintained at all times through the remaining unbroken circuits via the diodes that by-pass the broken circuits.

#### 4. Sampling Selector Switch

A selector switch is located in the console for the purpose of selecting the sensor circuit to be measured by the differential voltmeter. A second function of the switch is to ground the node of the circuit being measured, while simultaneously reconnecting the balance of the sensor circuits into a complete series connection, all in series with the constant current source. The switch was designed from a node and loop mathematical analysis which determined the minimum number of contact points and poles. The Centralab Company switch chosen for this application was selected primarily for its low contact resistance characteristics. Figure 4 illustrates the switching sequence provided by this switch.

#### 5. Differential Voltmeter

A differential voltmeter was selected for measuring potential drop across sensor circuits because of the high readout resolution requirements of the temperature measuring system. The Keithley Instruments Corp. Model 662 Guarded DC Differential Voltmeter was determined to be the most suitable for the application.

This voltmeter is a self-contained potentiometric system that accurately measures dc voltages. It has  $\pm 0.01\%$  limit of error from 100 millivolts to 500 volts full scale, 0.0025% repeatability,

and a reference supply stable to 0.0025% indefinitely without manual standardization.

The voltmeter is used in the 0.5 to 5.0 volt range when measuring individual sensor circuits, and in the 5.0 to 50.0 volt range when measuring total voltage drop across all body sensor circuits connected in series. Readout resolution of the voltmeter in the 0.5 to 5.0 volt range is 0.01 millivolts; in the 5.0 to 50.0 volt range it is 0.1 millivolts.

#### 6. Sensor Elements

The sensor elements were attached to the inside of a liquid cooled undergarment supplied by MSC. The undergarment (or suit) is made of a flexible loose weave cotton material. Numerous liquid coolant tubes of plastic were attached to the inside of the suit as supplied by MSC.

The sensor elements are composed of Formvar insulated 4 mil diameter high purity, fully annealed nickel wire sewn in a zig-zag pattern on the surface of 1.25" wide strips (or tapes) of flexible double knit cotton cloth. Fourteen separate sensor elements were fabricated, and appropriately interconnected to serve the seven individual sensor areas of the body. These were applied as follows:

- a. Forearms - 2 elements, 1 for each forearm
- b. Upper Arm - 2 elements, 1 for each upper arm
- c. Chest - 2 elements, 1 for each side of chest
- d. Back - 1 element
- e. Lower Trunk - 3 elements, covering main trunk,  
lower sides, and lower back of trunk
- f. Thighs - 2 elements, 1 for each thigh
- g. Legs - 2 elements, 1 for each leg

The sensor elements were attached to the inside of the suit, over the surface of the cooling tubes, with the wire side of the tapes toward the body. They were attached with Velcro tape (patented nylon material that adheres to a mating material when physically pressed together) in such a manner as

to not restrict the inherent flexibility of the elements within the suit and to make them readily removable for examination, adjustment or repair. The interconnecting wires from the elements were brought out of the suit through 14 pins of a 61 pin Micro-dot connector supplied by MSC.

Figures 5 and 6 show the suit with the elements installed. The suit was turned inside-out for these photographs. The elements were fitted to the suit while it was being worn by a man who closely approximated the dimensions for a mean percentile man as defined in the U. S. Air Force "Handbook of Instructions for Aerospace Personnel Subsystems Design," AFSCM 80-3, 15 April 1965 revision.

Two problems were encountered during the development of the sensor elements, as follows:

a. Originally, 2 mil diameter wire was planned for use as the sensor wire. Repeated breakage of this wire in sample elements was traced to over-stressing of the wire caused by the sewing operation. Different makes of sewing machines were tried to no avail. The problem was ultimately solved by changing from the 2 mil to a 4 mil diameter wire.

b. A much more difficult problem was encountered when the suit was first tested on the MSC temperature controlled manikin by AGC personnel during the week of 22 November 1965. At that time, when the suit was energized on the manikin, electrical grounding was detected between the sensor wires and grounded points on the manikin. Subsequent microscopic examination of the sensor wire showed that the wire insulation was severely cracked.

The suit was returned to Aerojet and the problem was subjected to an extensive evaluation. It was ultimately concluded that the wire insulation could be made to perform within the specified  $\pm 0.1^{\circ}\text{F}$  accuracy range for the overall instrument under dry body or moderate sweat conditions by changing from the original Isonel (Schenectady Chemicals Co.) insulation to Formvar (G.E. patented, poly-vinyl-acetal enamel) insulation. It was also concluded that it would not be possible, within the scope of the contract, to insulate the wire to the extent that

it would be operational within specifications while immersed in sweat or an equivalent solution. A complete discussion of this problem and the conclusions reached is provided in Appendix A.

The suit finally delivered to MSC under this contract contains sensor wire insulated with Formvar. The suit passed all specified acceptance tests at MSC. These tests did not include operation in high sweat environments.

#### IV. TESTS

Aside from the special tests noted in Appendix A which were directed toward improvement of sensor wire insulation quality, the following tests were conducted during the program:

##### A. ENVIRONMENTAL TESTS

##### 1. Approved Environmental Tests

Three environmental tests were approved by MSC for conduct in the program. These tests were conducted with results noted as follows:

##### a. Oxygen Environment

##### (1) Test Requirements

A sample of the tape shall be placed in an evacuated chamber. The chamber shall be pressurized with  $O_2$  to a pressure of 3.7 psia. The tape instrumentation shall be turned on at this pressure and remain on while the chamber pressure is increased to 19.7 psia in a period of 30 minutes. There shall be no evidence of deleterious operation caused by the  $O_2$  environment.

##### (2) Results

Three sample tapes were subjected to this test with 7 ma dc current impressed through the sensor wire. The temperature was held constant at 70°F. No change of current was detected during the test. The tapes were microscopically examined at 30 X after removal from the  $O_2$

environment. No deleterious effects were noted.

b. Temperature-Humidity

(1) Test Requirements

(a) A sample of the tape shall be placed in a temperature-humidity conditioned chamber. The chamber condition shall be set at 32°F and 10% humidity. The tape instrumentation shall be turned on and conditions maintained constant for thirty minutes. There shall be no evidence of deleterious operation caused by this environment.

(b) A sample of the tape shall be placed in a temperature-humidity conditioned chamber. The chamber conditions shall be set at 160°F and 95% humidity. The tape instrumentation shall be turned on and conditions maintained constant for thirty minutes. There shall be no evidence of deleterious operation caused by this environment.

(2) Results

Three sample tapes were subjected to each of the above tests with 7.0 ma dc impressed through the sensor wire. No change of current was detected during either test. Subsequent microscopic examination at 30 X revealed no deleterious effects.

c. Sweat Solution

(1) Test Requirements

(a) Conduct an operational test of three dry samples of tape with wire.

(b) Lay samples, wire down, on a metal plate and determine insulation resistance at 100 volts.

(c) Immerse three samples of tape in simulated sweat.

(d) Maintain sweat continuously at a temperature of 90° to 95° F for a period of thirty days.

(e) Remove one sample after each 10 day period and test as in (b) above.

(2) Results

Six dry sample tapes were tested for continuity then placed with the wire side down on a metal plate. The insulation resistance between the metal plate and the wire at 100 V dc was measured and found to be in excess of 500 megohms for each sample. The six samples were then totally immersed in a 0.85% NaCl solution in water. The solution temperature was maintained at 90° F to 95° F. Two samples were withdrawn from the solution each ten days and re-tested for insulation resistance on the metal plate at 100 V dc. All samples still read in excess of 500 megohms. Subsequent microscopic examination at 30 X revealed no deleterious effects.

As noted in Appendix A, this test was judged to be insufficient for purposes of detecting insulation leakage in a sweat environment in that there was no control over the degree of contact of the insulated wire with the metal plate, or over the degree of drying that occurred in the tape between the time it was removed from the bath and finally tested. Consequently, the test was superseded by a test that called for checking current leakage between the wire and a metal container while the sample tapes were totally immersed in an 0.85% saline solution in the container. Under these conditions, with the maximum operating voltage (32 V dc) impressed between the wire and the metal container, the insulation leakage was far in excess of the maximum allowable for operation within specified tolerances.

2. Additional Environmental Tests

In addition to the above approved environmental tests, the following test for fire or explosion hazard in a pure oxygen environment

was conducted:

a. Test

In order to assure that breakage of the sensor wires would cause no explosion or fire hazard in an oxygen environment, a sample tape was placed in a pure oxygen environment during the following tests:

- (1) Establish current through wire in excess of maximum possible current during operation.
- (2) Impress current through the wire at the maximum possible voltage during operation.
- (3) Stretch the tape to the point of breaking the wire under the above conditions.
- (4) Rejoin and separate the above break at least ten times in such a manner as to re-establish and re-break current flow.

b. Results

The maximum possible sensor current during operation of the instrument was calculated at 16 ma dc. Maximum possible output of the constant current source is 100 V dc. These figures are based on assumed failure of the built-in safety circuits. Testing under these conditions caused no fire or explosion, no observable sparks or arcing, and no deleterious effects on the insulation of the wire or the cloth tape when observed under 30 X microscopic examination.

B. FUNCTIONAL TESTS

1. Approved Functional Tests

One functional test was approved by MSC for conduct in the program. This was classified as the break test, and was conducted as follows:

a. Test Requirements

Make test loop of wire with length equivalent to that of one of the suit sections. Strip insulation from the wire for a distance of 1-1/2 inch and attach voltmeter leads to each end of stripped section and between each end of stripped section and ground. Connect to suit instrumentation console.

Turn on suit instrumentation and allow to stabilize. Cause a metal fatigue break by repeated bending and then bring the ends of the broken wire together several times. Record voltages and current during this procedure. Voltage shall not rise to dangerous levels.

b. Results

One sample loop of wire was tested as noted and results observed on an oscilloscope. Peak voltage across the break did not exceed 6.9 V dc.

2. Additional Functional Tests

In addition to the above approved functional test, the following functional tests were also conducted at Aerojet during the program (summary):

a. Sample Testing

(1) Tests

Three sample tapes were dry tested for:

(a) Continuity  
(b) Resistance at nominal 73°F  
(c) Insulation integrity of all exposed wire surfaces with 200 V dc metal surface probe and at 200 V dc while pulled tightly across a 3/16" radius metal rod.

(d) Insulation breakdown voltage while probed with a metal probe.

(e) Microscopic examination at 30 X

The samples were then flexed to 130% of their normal length 100 times and the above tests repeated.

(2) Results

No wire breaks occurred during the tests; the resistance did not change after repeated flexing; no breakdown of insulation occurred at 200 V dc; insulation breakdown occurred consistently above 375 V dc before and after flexing; no deterioration to insulation was noted under microscopic examination except at those points where deliberate insulation breakdown had been induced.

b. Fabrication Testing

(1) Tests

The following tests were conducted on all sewn tapes prior to their installation in the suit:

- (a) Continuity
- (b) Resistance at nominal 73°F
- (c) 100% probe of all exposed wire surface with a 200 V dc flexible metal probe.
- (d) 100% microscopic examination of all wire surface at 10 X.

Tests (a) through (c) were repeated after the tapes were installed in the suit.

(2) Results

No broken wires were detected; the resistance of the individual sensor circuits varied only slightly before and after assembly, consistent with the varying room temperature and the slightly modified wire lengths that resulted from wiring the tapes to the connector; no insulation breakdowns occurred during 200 V dc probe; no breaks in the insulation were noted under the microscope.

Figure 7 lists the resistance values measured for the various sensor circuits of the suit that was finally delivered to MSC. These are nominal values since they were measured in an open room at a nominal air temperature of 73°F.

C. TESTS AT MSC

1. Integration

The components of the instrument were integrated at MSC on 24 May 1966 by Aerojet personnel as follows:

- a. Confirmed that the connections of the suit-to-console wiring were compatible.
- b. Checked constant current source and differential voltmeter to confirm proper connections for negative grounding.
- c. Checked functional operation with suit connected to console to assure all sensor circuits were operating. Tested by selecting one circuit at a time and causing localized temperature changes by placing the hand on the various selected circuits in the suit. All circuits were noted to be connected properly, and operational. The suit was placed on a table top in open air during this test.
- d. Checked MSC manikin for common ground with the T-suit console. All metallic points of the manikin were found to have a common ground with the chassis except for the metal pin through the thigh of the manikin.
- e. Checked for voltage spikes between all metal points in the manikin and the T-suit chassis while simultaneously operating the T-suit and the manikin through all normal modes. Reading from an oscilloscope set for 5 mv full scale vertical deflection, no spikes of any sort were noted. The suit was not yet installed on the manikin during this test.
- f. Installed the suit on the manikin. No problems were encountered.
- g. Rechecked functional operation of the suit connected to the console, with the suit installed on the de-energized manikin. All circuits operated properly.

h. Repeated test g. while operating the manikin in a rising temperature mode. All T-suit circuits operated properly. The differential voltmeter indicated a rising voltage for all circuits, consistent with the rising temperature of the manikin. No attempt was made at this point to correlate actual temperature readings in that the MSC manikin temperature controls were not functioning properly.

## 2. Calibration and Acceptance Tests

Modification No. 3 to contract MAS 9-4067 relieved Aerojet of any responsibility to calibrate the instrument to meet specifications or to engage in testing to verify compliance with the specifications. However, on 25 May 1966, Aerojet personnel assisted MSC personnel in performing the following tests. (The MSC manikin temperature controls had been restored to full operation for these tests.)

a. With the suit on the de-energized manikin at room temperature, and with the T-suit console turned on and stabilized with 7.0 ma dc flow in the sensor circuits, the balancing resistors for all sensor circuits were adjusted to provide a nominal 2.1 V dc drop across all individual circuits and 4.2 V dc drop across the "arms" (forearms plus upper arms) circuit.

b. Calibration runs were then conducted with the suit on the manikin, and with the total body temperature of the manikin successively set at 79.9°F, 89.9°F and 99.9°F. Differential voltmeter readings were taken for each sensor switch position on the T-suit console. Results of these readings are provided in Figure 8.

These figures were used as the basis for determining the value of K for three representative sensor circuits (legs, arms, and body) in the following equation (See Section III.A.2):

$$T_x = T_c + \left( \frac{V_x - V_c}{K} \right)$$

where:

$T_x$  = unknown temperature in  $^{\circ}\text{F}$

$V_x$  = differential voltmeter reading in volts at the unknown temperature

$T_c$  = calibration temperature in  $^{\circ}\text{F}$

$V_c$  = differential voltmeter reading in volts at the calibration temperature (different for each sensor circuit)

$K$  = the change in volts per  $^{\circ}\text{F}$  change in sensor temperature (different for each sensor circuit)

The value of  $K$  for each of the selected circuits, as determined from the data shown in Figure 8 is:

Legs -  $K = .00283 \text{ volts}/^{\circ}\text{F}$

Arms -  $K = .005713 \text{ volts}/^{\circ}\text{F}$

Body -  $K = .02333 \text{ volts}/^{\circ}\text{F}$

Also from Figure 8, selecting  $79.9^{\circ}\text{F}$  as the calibration temperature, corresponding values for  $V_c$  are:

Legs -  $V_c = 2.1995 \text{ volts}$

Arms -  $V_c = 4.3999 \text{ volts}$

Body -  $V_c = 15.4004 \text{ volts}$

c. Next, the manikin body temperature was readjusted to a temperature unknown to the T-suit instrument operators. Voltage readings were taken of the arms, legs and body sensor circuits, and the values were applied to the above equation as a basis for determining a temperature to compare with actual manikin temperature. The following voltages were read:

Legs -  $V_x = 2.22672 \text{ volts}$

Arms -  $V_x = 4.45710 \text{ volts}$

Body -  $V_x = 15.6417 \text{ volts}$

Applied to the temperature equation, these values yield the following temperatures for the selected sensor circuits:

Legs -  $T_x = 89.519^{\circ}\text{F}$   
Arms -  $T_x = 89.912^{\circ}\text{F}$   
Body -  $T_x = 90.243^{\circ}\text{F}$

The maximum deviation of these readings from the manikin reference temperatures occurred in the case of the legs, where the manikin instrumentation indicated a temperature of  $89.8^{\circ}\text{F}$  existed. That is, the T-suit reading for the legs was  $89.8 - 89.5193 = 0.2807^{\circ}\text{F}$  low. The contract specification allowed a  $0.5^{\circ}\text{F}$  difference between the T-suit and manikin readings under these test conditions. The deviation of the arms and body readings was less than  $0.1^{\circ}\text{F}$ . These results are considered very satisfactory in that the calibration procedure had been rapidly performed under conditions that did not assure absolute steady-state manikin temperatures. Ultimate calibration of the instrument under carefully controlled conditions should assure even more accurate results.

d. Finally, the suit was removed from the manikin and donned by the MSC Project Engineer. Readings were taken on all sensor circuits with the subject at rest. Typical integrated skin temperatures were read as follows:

Legs -  $91.010^{\circ}\text{F}$   
Arms -  $91.500^{\circ}\text{F}$   
Body -  $91.585^{\circ}\text{F}$

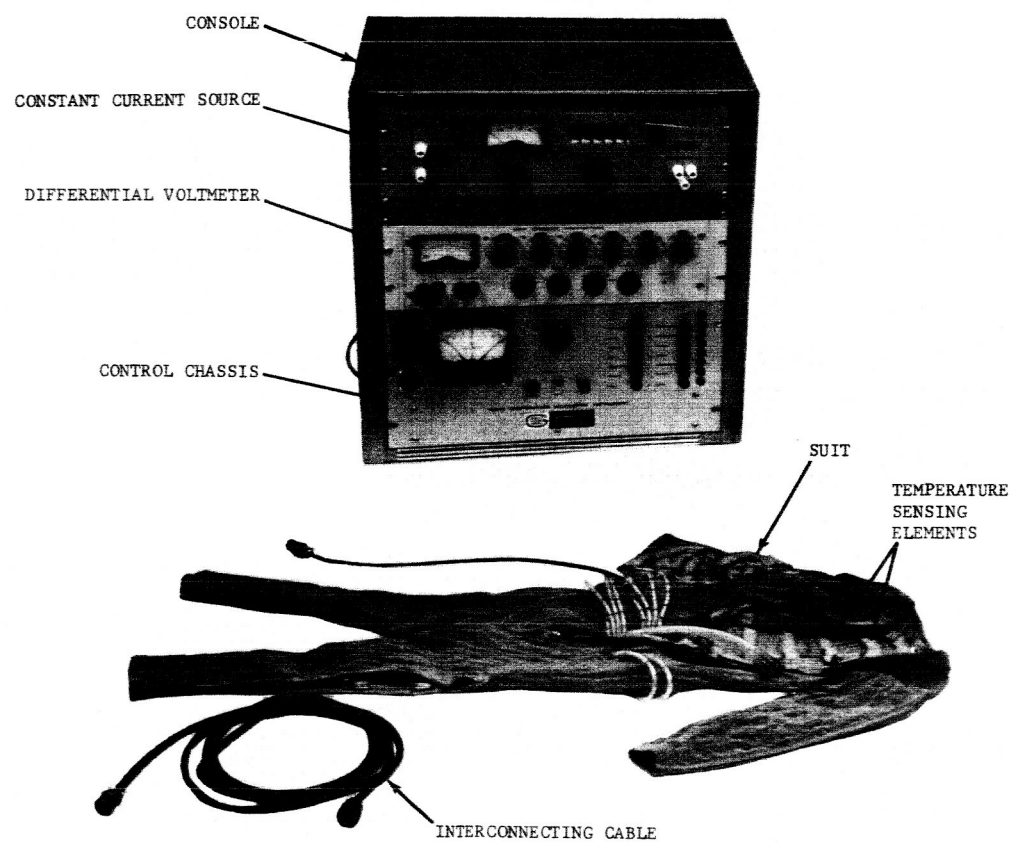
After brief exercise, the subjects body temperature rose to  $91.747^{\circ}\text{F}$ .

## V. CONCLUSIONS AND RECOMMENDATIONS

All tests indicate that the instrument performs as specified under dry suit operating conditions. The degree to which it will meet specifications under heavy sweat conditions is unknown at this time; although it is known that it will not perform within specifications when the sensors are totally

immersed in a simulated sweat solution. This failure is directly attributable to shorting of the sensor wires through the saline solution that penetrates minute cracks and pinholes in the sensor wire insulation.

Appendix A explains the difficulties encountered by Aerojet in attempting to solve the insulation problem. It is believed that the problem can be solved through a program to research wire insulations and sewing techniques. A proposal for such a program was submitted to MSC in January, 1966 (Reference Aerojet Proposal Number LS-64006C, dated 26 January 1966.)



11-E-02

FIGURE 1 - SKIN TEMPERATURE MEASURING INSTRUMENT

FIGURE 2 - BLOCK DIAGRAM, MAJOR COMPONENTS

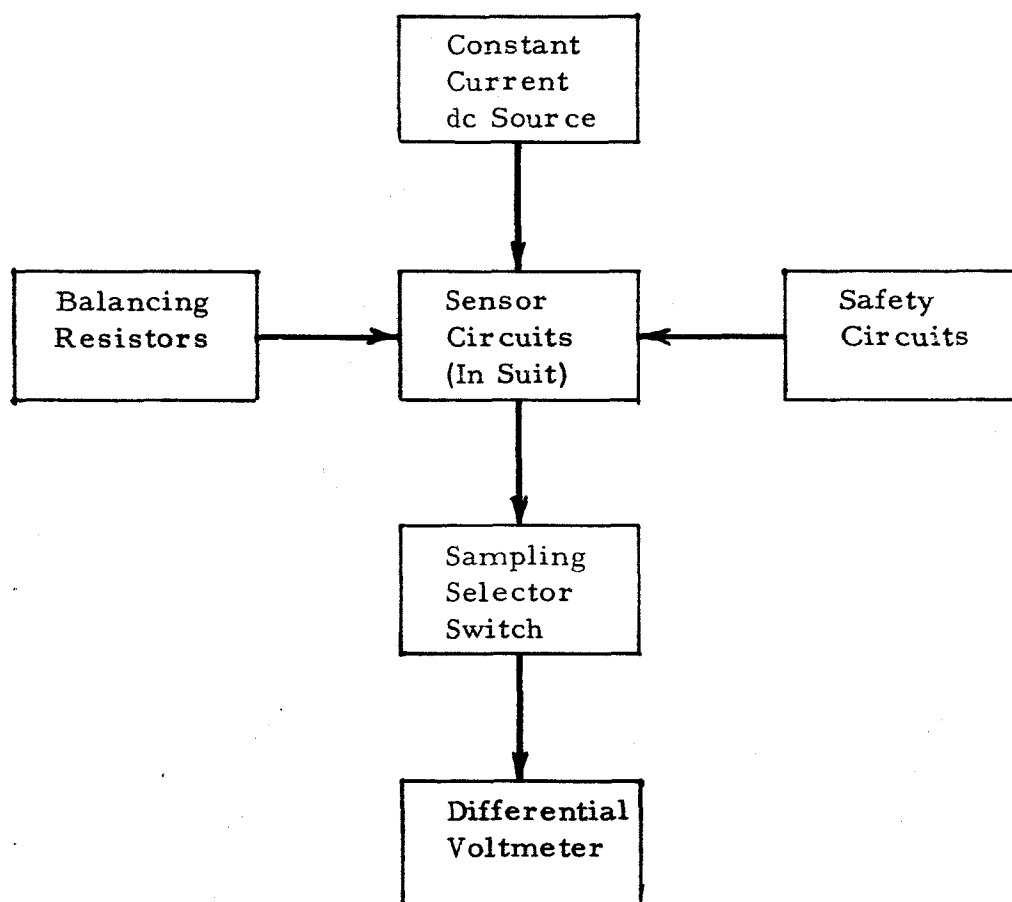
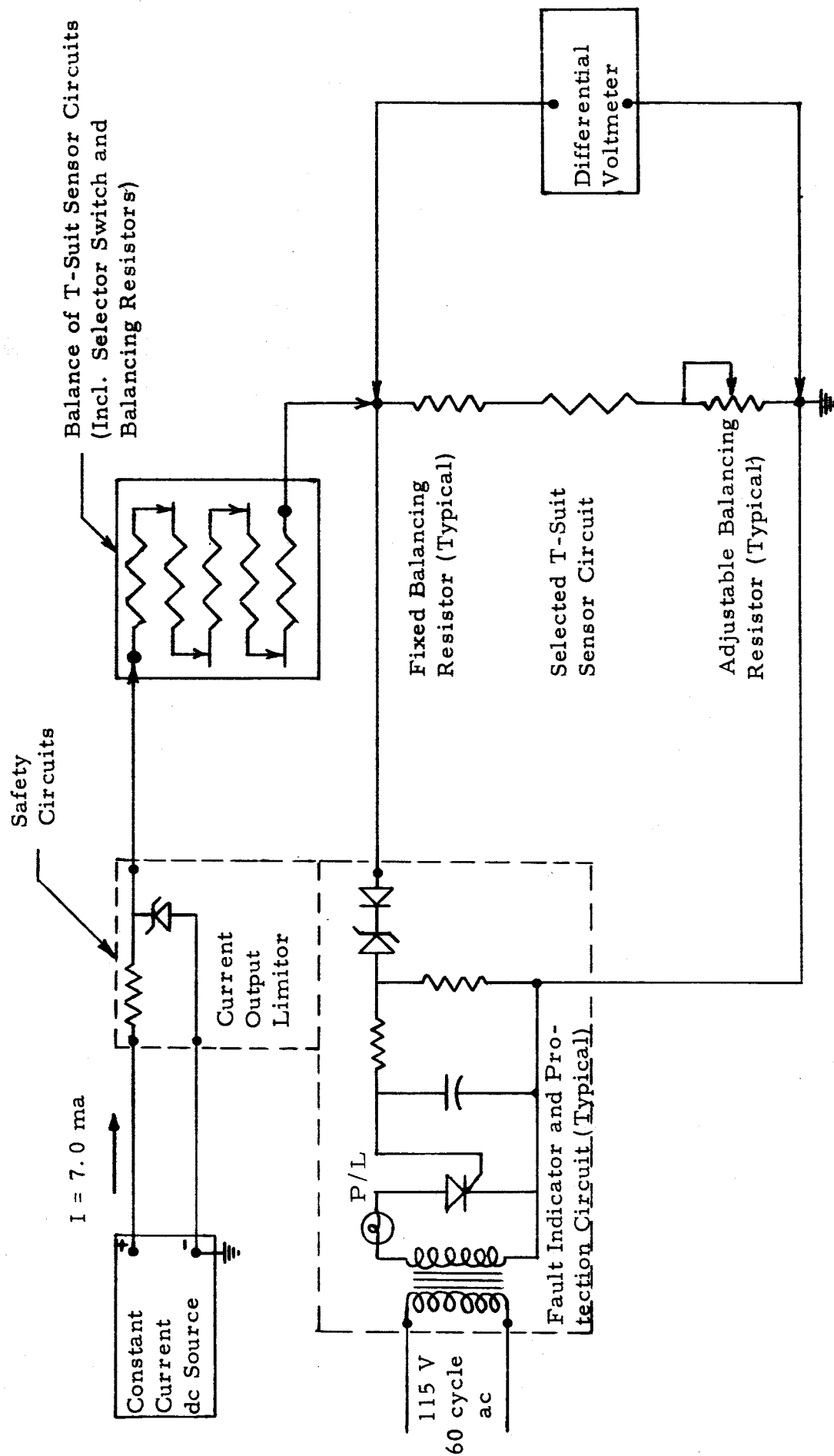


FIGURE 3 - SKIN TEMPERATURE MEASURING INSTRUMENT FUNCTIONAL SCHEMATIC DIAGRAM



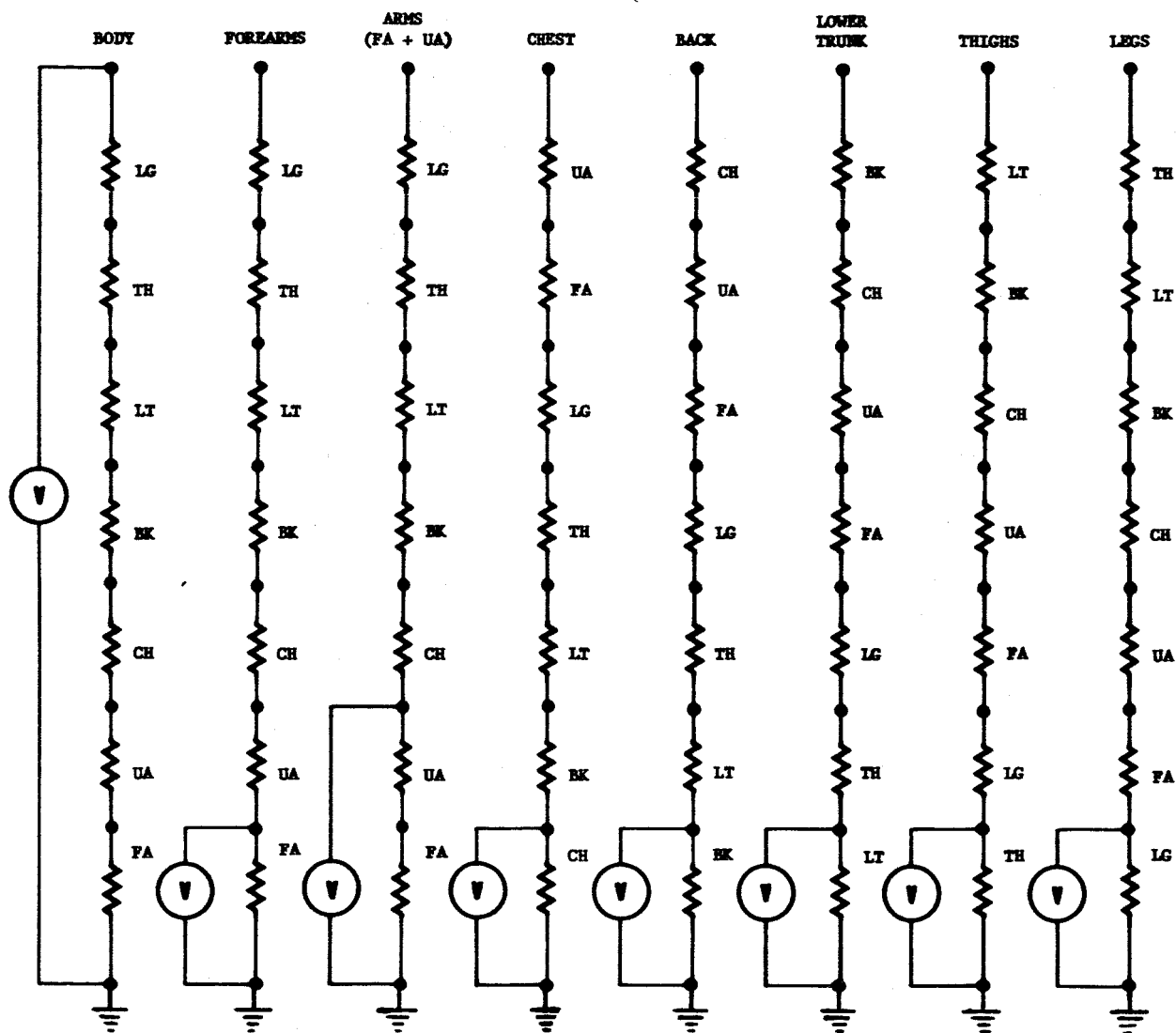


FIGURE 4 - SWITCHING SEQUENCE



FIGURE 5 - SUIT, FRONT INSIDE - TAPES INSTALLED



FIGURE 6 - SUIT, BACK INSIDE - TAPES INSTALLED

# FIGURE 7 - SENSOR ELEMENT RESISTANCE VALUES

(Measured at Nominal 73°F in Air)

<u>Pins</u>	<u>Circuit</u>	<u>Resistance (Ohms)</u>
1-2	Legs	142
3-4	Thighs	200
5-6	Lower Trunk	285
7-8	Back	142
9-10	Chest	163
11-12	Upper Arms	160
13-14	Fore Arms	130

FIGURE 8 - CALIBRATION DATA, SUIT ON MSC MANIKIN

Test Position	Temperature, °F		
	79.9°	89.9°	99.9°
Legs	2.1995 V	2.22774 V	2.25615 V
Thighs	2.2003	2.23787	2.27477
Lower Trunk	2.2004	2.24857	2.29616
Back	2.2003	2.22798	2.25605
Chest	2.2001	2.23360	2.26778
Fore arms	2.2005	2.22592	2.25106
Arms	4.3999	4.45698	4.51424
Body	15.4004	15.63370	15.86710

## APPENDIX A

to

### FINAL REPORT UNDER CONTRACT NAS 9-4067

#### Sensor Element Electrical Insulation Problems Encountered During Development of An Instrument to Measure Integrated Skin Temperatures

Sensing element insulation difficulties were first noted after a completed suit was delivered to MSC under Contract NAS 9-4067 during the week of 22 November 1965. The initial calibration tests of the garment on the manikin revealed high resistance electrical paths between the wire-sewn tapes and the grounded metallic joints on the manikin. Prior to shipment of the suit, samples of each tape had successfully passed the approved environmental tests (oxygen environment, temperature-humidity, sweat and break). Upon return of the suit to Aerojet, none of the tapes would satisfactorily pass these tests.

The subject suit was sewn with Isonel coated, 4 mil, high purity fully annealed nickel wire. Isonel is a Schenectady Chemicals Company insulation (same as Phelps-Dodge patented Poly-Thermaleze 200) coating that is purported to be characterized by a high degree of flexibility, good film adhesion, smoothness, good film continuity, high solvent resistance and excellent electrical properties. Microscopic examination of the wire in the suit after its return to Aerojet revealed gross cracking and flaking-off of the insulation from the wire. In view of this and the fact that the tapes would no longer pass the pre-shipment environmental tests, it was concluded that the insulation had mechanically failed as a result of handling during shipment and/or at the time of placement of the suit on the manikin.

Aerojet engaged a magnet-wire consultant to aid in evaluation of the problem. He stated that this application of magnet-wire was not consistent with the intended use of the wire, and consequently, commercial insulating standards would not routinely meet the requirements. He stated that magnet wire insulation was primarily intended to provide turn-to-turn spacing

between coil wires, in relatively dry environments, to the extent that occasional pin-holes or hair-line cracks are permissible under NEMA standards (Reference NEMA Publication No. MW 15-1959, Paragraph 5.3.2). It was concluded, however, that a reasonable chance of success existed by use of a more flexible and adhering insulation, followed after sewing by application of a final film coating of insulating material to seal any process pin-holes or cracks that develop during the sewing process. Accordingly, the following steps were taken in an attempt to deliver a suit to meet specifications.

1. Additional 4 mil, fully annealed high purity bare M1 wire was ordered.

2. Upon receipt at Aerojet, samples of the wire were microscopically examined for evidence of any surface roughness conditions that might be detrimental to the coating process. No high spots over the mean wire diameter of greater than .0002 mils were noted.

3. Formvar insulation (G.E. patent, poly-vinyl-acetal enamel) was selected as the best known candidate for coating the wire based on the facts that (a) it is commonly available, (b) application techniques are fully developed, (c) it is tough and flexible and (d) it meets all basic electrical insulating requirements.

4. A special wire coating run was made at the Hudson Wire Co., Winstead, Conn. under the personal supervision of their Manager of Engineering. Hudson was selected because of their unquestioned qualifications in the magnet-wire field.

5. The final coating increased the resultant outside diameter to .0049" - .005", i.e., the average coating thickness was .00045" - .0005". The following NEMA standard tests were conducted by Hudson (Reference NEMA Publication No. MW 15-1959).

5.2.1.2 Adhesion - The sample was jerked to the breaking point and no visible cracks found. The enamel adhered to the conductor at all points.

5.3.1 Dielectric Strength - Tested at 4500 volts using the twist method.

5.3.2 Continuity - A length of 100 ft exhibited no insulation breaks or discontinuities when tested in mercury at 100 volts dc.

5.4.2 Completeness of Cure - The sample passed the toluol-alcohol test.

6. Further tests of the coated wire were conducted at Aerojet as follows:

a. Microscopic examination at 90 X before and after 10% elongation of wire, turning of wire around a 10 mil mandrel, scraping of wire with fingernail and kinking of the wire revealed no visible discontinuities, cracks or pin-holes, or any eccentricities of the wire within the insulating jacket.

b. Tests of the insulation at 500 volts ac to ground after the above abuses when wrapped around the mandrel, twisted in pairs or compressed against a metal plate revealed no breakdowns.

7. The Singer sewing machine that was used to sew the original suit was examined in detail for burrs, sharp edges or unreasonable tensions that would tend to breakdown insulation integrity. All edges and surfaces were found to be smooth, although some of the changes in direction required of the wire in the sewing operation were judged to be more harsh than is desirable (the wire works off of the bobbin). Samples were run and the bobbin tension was adjusted to a minimum consistent with a good sewing pattern. At the time of winding the wire on the bobbins, a very fine coating of Isopar L lubricating oil (Humble Oil Co. winding oil) was put on the wire to minimize abrasion.

8. Sewn samples were subsequently held firmly between metal plates and the maximum voltage before breakdown was checked to ground. Voltage breakdown consistently occurred between 350-400 volts ac (rms). This indicated that some cracking of the wire had occurred during the sewing operation even though they were not observable at 90 X under a microscope.

9. Several sewn samples were subsequently degreased with petroleum ether and treated by carefully painting solutions of (a) cellulose-acetate-butyrates (EAB-171-15, Eastman Chemical Products Co.) or (b) Lenton (Dupont

acrylic) onto the wires. The Lecton coated samples, after cure, showed no evidence of breakdown up to 500 volts ac (rms) when pressed between metal plates. The sample tapes did lose some of their moisture absorbent capability as a result of absorbing the Lecton solution into the cotton during the painting operation. The effect was judged to be minor, however. Preliminary saline water wetting tests showed no evidence of insulation leakage with operating voltage (7 volts dc) applied to ground.

10. Tapes for the entire suit were fabricated with the lubricated 4 mil Formvar coated wire. These were then degreased and coated with the Lecton solution, and subsequently oven cured at 190<sup>o</sup>F for 4 hours. The resulting samples were generally unacceptable. Due to the fact that several people participated in the coating process, some samples were saturated with Lecton beyond usefulness from the absorption and flexibility standpoint, and other samples that were treated with less Lecton were judged acceptable.

11. Subsequent testing of these samples showed that they would satisfactorily pass a salt water immersion test until they had been flexed several times, after which they exhibited gross breakdown in insulation integrity.

12. Further sample testing was conducted using a variety of insulating coatings and application techniques in an attempt to resolve the problem. As a part of this testing, thin sheets of various materials such as papers, cloths and plastics were sewn between the wire and the cotton tape in an attempt to provide a temporary barrier to prevent the cotton from absorbing the coating material during coating operations. All techniques and coating materials failed. Many samples appeared to be satisfactory in the salt water immersion tests until after they were flexed several times. Additional coating materials tested unsuccessfully during this series were:

EpoxyLite #9653 (Polyurethane)

EpoxyLite #8788 (Polyurethane)

Hysol #PC-15 (Polyurethane)

Hysol #PC-17 (Epoxy)

Hysol #PC-18 (Polyurethane)

BC 340 Insulating Varnish

Chemical Electronic Engr. Inc. Plastic Sealer

All experimental insulation work was stopped at this point. The conclusions reached by Aerojet as a result of this series were:

1. We do not have a wire or sewing technique that can be expected to meet specified sweat environments.
2. We can fabricate and deliver a suit that will not ground out to the manikin at potentials under 300 volts ac. (Maximum possible operating potential of the suit to its test console ground is 33 volts dc). This suit should also operate satisfactorily on a man under relatively dry conditions.
3. The sewing operation is instrumental in breaking down insulation integrity.
4. Coating wire after it has been sewn onto cotton knit cloth appears to be an impractical process.
5. Pin-hole free wire that will successfully survive the present sewing operation is not readily available.
6. Total saline water immersion tests are the only way to be sure that pin-hole/crack-free insulation exists in the samples, before and after flexing.
7. Pin-hole/crack-free wire is necessary in saturated sweat environments in order to maintain inter-wire current leakage to a minimum consistent with the specified  $\pm 0.1^{\circ}\text{F}$  accuracy range of the overall instrument.